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MEASUREMENTS OF ATMOSPHERIC X AND GAMMA RAYS-BALLOON EXPERIMENTS AT SUBANTARCTIC REGION

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14. Abstract/Notes

*The results of two stratospheric balloon experiments conducted to measure the atmospheric X and gamma rays are presented. These experiments, conducted at Comandante Ferraz base in subantarctic region, have provided the spectrum of ground radioactivity in gamma rays (0.2 to 2.9 MeV) and atmospheric X-ray spectra at different altitudes. We specifically chose to discuss the observed ceiling spectrum of X-rays in the 28 to 180 KeV region observed at 7.0 g . cm$^{-2}$. We have utilized the data of other experiments with different telescope geometries, to evaluate the buildup effects due to cosmic ray secondaries in atmosphere. This behaviour, previously studied for atmospheric gamma rays, permitted us to compare the up/down flux ratios to explain the observed atmospheric X-ray spectrum.*

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Apresentam-se os resultados de dois vôos de experimentos a bordo de balões estratosféricos para medir raios X e gama atmosféricos. Estes experimentos, realizados na base Comandante Ferraz na região subantártica, forneceram o espectro da radioatividade do solo em raios gama (0,2 a 2,9 MeV) e os espectros atmosféricos em raios X em diferentes alturas. Particularmente, escolheu-se para discussão o espectro de raios X observado no teto, em 7 g $cm^{-2}$, na região de energia de 28 a 180 KeV. Utilizaram-se os dados de outros grupos com geometria de telescópios diferentes, para desenvolver os efeitos de crescimento devidos aos raios cósmicos secundários na atmosfera. Este comportamento, previamente estudado para raios gama atmosféricos, permitiu comparar a razão "up/down" dos fluxos para explicar o espectro de raios X atmosféricos observado.

The results of two stratospheric balloon experiments conducted to measure the atmospheric X and gamma rays are presented. These experiments, conducted at Comandante Ferraz base in subantarctic region, have provided the spectrum of ground radioactivity in gamma rays (0.2 to 2.9 MeV) and atmospheric X-ray spectra at different altitudes. We specifically chose to discuss the observed ceiling spectrum of X-rays in the 28 to 180 KeV region observed at 7.0 g . $cm^{-2}$. We have utilized the data of other experimenters with different telescope geometries, to evaluate the buildup effects due to cosmic ray secondaries in atmosphere. This behaviour, previously studied for atmospheric gamma rays, permitted us to compare the up/down flux ratios to explain the observed atmospheric X-ray spectrum.

## INTRODUCTION

The atmospheric X and gamma ray events observed by detectors at stratospheric balloon altitudes are the products of complex electromagnetic interactions of cosmic ray secondaries with the constituents of the atmosphere. The complex nature of these interactions prevent a direct translation of the observed spectrum to specific photon-particle or photon-photon interactions. As such the atmospheric background has been quantified in gamma ray energy range in terms of source function (Ling, 1975). To evaluate this source function dependent on energy, atmospheric depth and geographical position, semiempirical models have been postulated from the observed fluxes.

The observed X and gamma ray atmospheric background has been verified in experiments to have latitudinal dependence, consistent with the increase in cosmic ray flux at higher latitudes (Jayanthi et. al. 1982). In addition to this steady cosmic ray produced component, at higher latitudes near around auroral regions and in South Atlantic Anomaly region temporal flux increases by large factors have been observed (Anderson, 1960; Tepley and Wentworth, 1962; and Martin et. al., 1972).

The Comandante Ferraz base at Antarctic is situated at high latitude to observe large fluxes of atmospheric X and gamma ray background and perhaps temporal events due to auroral bursts, pulsations and precipitation events in the flight trajectory of the balloon as this region borders both South Atlantic Anomaly and southern auroral zone (Seward, 1963). We have conducted two balloon experiments, one with X-ray detector and another with gamma ray detector, in this region to observe atmospheric background. We describe the experiments and the results obtained in these balloon experiments.

## EXPERIMENTS AND FLIGHT DETAILS

The telescope for X-ray observations employed a 1.25cm thick NaI(Tl) scintillation detector (dia: 7.62cm) with an aluminum entrance window of 81 micron thick, to allow X-ray detection above 25 keV. The detector's view angle for X-rays incident in the forward direction was defined by a passive graded shield consisting of cylindrical sheets of 2mm thick brass and 1mm thick lead materials. This shield, which extends to enclose the sides of the X-ray crystal, permitted FWHM ~24.5$^{0}$ and ~30$^{0}$ at 40 keV and 122 keV respectively. An active anticoincidence detector of 1.25cm thick NE 102 plastic scintillator, in the shape of cylindrical well, enclosed the X-ray detector assembly and the graded shield to prevent charge particle interactions which may mimic X-ray events in the NaI(Tl).

The X-ray detector events not in coincidence with particle shield detector, were utilized for energy and temporal analysis. A discrete, linear pulse height analyser (PHA) sorted an equivalent of 28.5 to 185 keV X-ray events into 31 bins. The same events in parallel were analysed by a time analyser with a time resolution of ~64 msec. Data from PHA, time analyser, total count rate and anticoincidence count rate were accumulated for 2 minutes of duration in the payload for transmission by FM/FM telemetry along with pressure data.

The gamma ray telescope was an omnidirectional one and employed a 7.62 x 7.62cm cylindrical NaI(Tl) detector for monitoring gamma ray events. An NE 102 plastic scintillator of ~1.25cm thick, in the shape of well, covered the NaI(Tl) detector assembly on the bottom and sides to reject particle events in the gamma ray detector. A 256 channel analyser monitored the gamma events in the 0.200 to 5.3 MeV energy domain.

The PHA analysed gamma ray events were accumulated for duration ~1 minute before entering the FM/FM telemetry for transmission along with the total count rate, anticoincidence rate and pressure sensor data.

Preflight calibrations have been extensively conducted on both X-ray and gamma ray payloads for the detector response-linearity and resolution of the detector and electronics, angular response of the telescope and anticoincidence rejection efficiency etc., with various radioactive sources $Am^{241}$, $Eu^{152}$, $Cs^{137}$, $Co^{60}$ and ground radioactivity. The X-ray telescope had typical resolution of ~32% at 59.7 KeV ($Am^{241}$). In Fig. 1, we have shown the detector response for $Am^{241}$ and $Eu^{152}$, as well as the PHA linearity for this telescope. The typical resolution for gamma ray detection was 14.4% at 0.51 MeV ($Na^{22}$). The anticoincidence was adjusted at ~200 KeV by monitoring the Compton response for $Cs^{137}$ and $Co^{60}$ sources. The rejection efficiency was adjusted at ~85% for both the telescopes.

As the launch logistics at Comandante Ferraz base (58°24'W, 62°05'S) favoured launches of small balloons, the payload was covered with Styrofoam material for support and thermal insulation of the individual components of the telescope, and no ballast or recovery system was attached. No on board calibration and no graded shield for preventing X-rays entering from bottom side were provided for the X-ray telescope. The Raven balloon of ~7500m³ with the gamma ray pay load (~43kg) was launched on February 10, 1985 at 06:00UT. The payload which was functioning till 15 minutes after launch (~600 mbars altitude) suddenly ceased transmission. The X-ray payload launched on February 21, 1985 at 06:30UT, with a similar balloon, attained a ceiling altitude of 7.0g . $cm^{-2}$ after 100 minutes of ascent. The telemetry noise, especially frame synchronization, permitted us to recover only 24 minutes of data at various altitudes of balloon ascent and 4 minutes of data at float altitude.

## RESULTS AND DISCUSSION

The premature termination of the gamma ray experiment flight permitted us to present the terrestrial activity obtaining at Comandante Ferraz base in Antarctic (Fig. 2). The continuum spectrum, measured in the 200 KeV to 2.9 MeV range, with the 7.62cm thick NaI(Tl) crystal, exhibited a power law slope with steep decline in flux beyond 2.8 MeV. The superposed peaks at 1.46 MeV ($K^{40}$) and at 2.6 MeV ($Th^{228}$) *are due to detector contamination and natural radioactivity. We have* presented in the same figure the ground activity measured at Juazeiro do Norte ($7^{0}3$'S, $39^{0}12$'W) with a similar omnidirectional telescope consisting of a 10 x 10cm cylindrical NaI(Tl) detector (Jayanthi et al., 1982). The flux in the continuum at the two places is essentially the same, as the 10 x 10cm crystal has higher efficiency of detection. However, it is clear from the total flux in the $Th^{228}$ line, the radioactivity at Juazeiro do Norte is greater than that was measured at Comandante Ferraz base, at least by factor ≥2. This is expected as Juazeiro do Norte is situated in a known radioactive mineral region.

The performance of the detector and associated electronics of the X-ray payload functioned satisfactorily during the ascent to the ceiling altitude of 7.0g . $cm^{-2}$. However, the noise in the telemetry permitted us to obtain useful data for two broad segments of altitude - 985 to 215 mbars and 22.2 to 6.85 mbars. In Fig. 3, the count rate time profile of 30 to 100 KeV and 100 to 180 KeV x-rays is shown. We notice the characteristic fall in the count rate, in the initial phase, due to reduction in the terrestrial activity at the payload at 900 - 980 mbars altitude. As the balloon ascends further, the count rates show gradual increase and are expected to increase till Pfotzer maximum (~120 - 150 mbars). After this expected maximum, they decline to float altitude values as shown in the figure. As the cosmic ray secondaries cascade in the atmosphere, the production rates of X-rays increase till Pfotzer maximum, as this altitude corresponds to mean free path lengh of the cosmic ray pion component. The observed count rate spectra of the atmospheric X-rays at different altitudes are plotted in Fig. 4. The spectra at different depths have similar index of power law ~2.2 in the energy range of 50 to 150 KeV and the flux values present the expected increase. The observed X-ray spectrum at ceiling altitude of ~7g . $cm^{-2}$ is shown as a continuous histogram in Fig. 5. In the same figure, we have for comparison plotted the high altitude observations of Anderson (1960) at 9.0g . $cm^{-2}$, Peterson (1963) at 6.0g . $cm^{-2}$, and Bleeker (1970) at 4.3g . $cm^{-2}$. The ceiling spectrum has been known to consist of three distinct components - the cosmic ray induced background (CRIB) in the detector, the atmospheric X-rays and cosmic X-rays. As discussed by Kasturirangan et al. (1971), the individual contributions of these components depend on the geomagnetic activity, geomagnetic latitude or cutoff rigidity (CR) and altitude of observations, in addition to the particular detector and telescope configuration employed. The shape of the spectrum in all these observations is essentially similar in the 50 - 150 KeV range with average index -2.0 $\pm$ 0.2, considering the differences in the detector systems. The flux differences essentially arise out of the above mentioned differences of the detector system and telescope geometry. As such the omnidirectional telescopes of Anderson (1960) and Peterson (1963) are expected to register higher flux values in comparison with our observations and Bleeker's (1971). It is more interesting to try to understand the experimental values observed by Bleeker (1971) at CR ~5 GV and the present experiment at ~3.1 GV. These two experiments have employed detectors of equal thickness and similar opening angles for forward X-rays. We attribute the flux differences to the upward incident X-rays which have access to the detector in our experiment, as it has no graded shield on the bottom side, unlike the experiment of Bleeker (1971). Besides, as the $k_p$ on the day of our experiment is $\leq 2$, we discount excess due to particle precipitation or auroral activity.

We have originally planned to evaluate the source function of atmospheric X-rays with continuous data in the 7 to 200g . cm$^{-2}$ altitude range. This evaluation of the source function, by semi-empirical methods with the observed data, was employed in gamma rays by Ling (1975). This would have permitted us to estimate in detail the angular variation of flux of atmospheric X-rays, which is not done so far. As this was not possible with our limited data, we have derived the flux ratios of atmospheric X-rays incident in the downward and upward directions. We compare the up/down flux ratio of atmospheric X-rays for consistency with the values obtained in gamma ray range to justify the observed ceiling spectrum. We have estimated the contribution of cosmic ray induced background (CRIB) in our detector by interpolation to our cutoff rigidity and altitude values from the observations of Bleeker and Deerenberg (1970), who conducted identical experiments at three different latitudes. The spectrum of atmospheric X-rays obtained after subtracting the CRIB for 7g . $cm^{-2}$ is shown in Fig. 5. The atmospheric spectrum is steeper than the ceiling spectrum, especially at higher energies. In conjunction with their atmospheric flux values at different altitudes of the 25 to 110 KeV X-rays, we have evaluate the upward and downward fluxes at different altitudes for our detector configuration and cutoff rigidity. We have plotted in Fig. 6 this up/down flux ratio R against the atmospheric depth for three intervals of energy - 28.5 to 60 KeV, 60 to 92 KeV and 92 to 123 KeV. We have taken the statistics into consideration and did not include systematic errors. In all the channels, this ratio R increases with decreasing depth by factors ~1.5. Even including the cosmic X-rays contribution (less than 20 percent of total flux), whose effect is to increase the R value, this variation with depth shows increase in source function value as in gamma rays. The value of the ratio at ceiling altitude of 7g . $cm^{-2}$ varies from 2.57 to 1.55, with an average value of ~2.2 ± 0.35 for 28 to 128 KeV atmospheric X-rays.

From the observations of gamma ray flux, in a 7.62 x 7.62cm NaI(Tl) detector, Ling (1975) evaluated the source functions and obtained for R values ~2.4 and ~4.7 at 300 KeV and 1 MeV, respectively, for atmospheric γ-rays at 7g . $cm^{-2}$ altitude. The experiment by Hsieh (1978), with a Compton telescope at 3.5 mbar float altitude, has provided for the up/down flux ratios ~3.7, 3.85 and 5.6 at 2.5, 5.0 and 10.0 MeV, respectively. The atmospheric buildup of flux, due to the cascade interactions of cosmic ray secondaries, is expected to give lower values of R for X-ray region compared to gamma rays, as the later have higher absorption mean free path lengths in the atmosphere. The up/down flux ratio value of R ~2.2 for the 28 to 123 KeV X-rays is not inconsistent with the higher gamma ray values. Thus we believe the atmospheric spectrum observed in our experiment is due to cosmic ray secondary interactions in atmosphere, with predominant contribution from upward incident X-rays.

## ACKNOWLEDGMENTS

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# MEASUREMENTS OF ATMOSPHERIC X AND GAMMA RAYS - BALLOON EXPERIMENTS AT SUBANTARCTIC REGION

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FIGURE CAPTIONS

Fig. 1 - The response of X-ray detector to $Eu^{152}$ and $Am^{241}$ radioactive sources. Also is shown the PHA energy calibration.

Fig. 2 - The ground radioactivity histograms at Comandante Ferraz (thick line) and at Juazeiro do Norte (thin line) in gamma ray energy region.

Fig. 3 - Time history of X-ray count rate during the ascent of balloon to ceiling. Each observation corresponds to counts accumulated in 2 minutes time period.

Fig. 4 - The observed X-ray spectra at different altitudes.

Fig. 5 - The ceiling and atmospheric spectra observed in our experiment. High latitude ceiling spectra observed by other experimenters are also shown.

Fig. 6 - Variation of the computed up/down atmospheric X-ray fluxes ratios with altitude and energy.

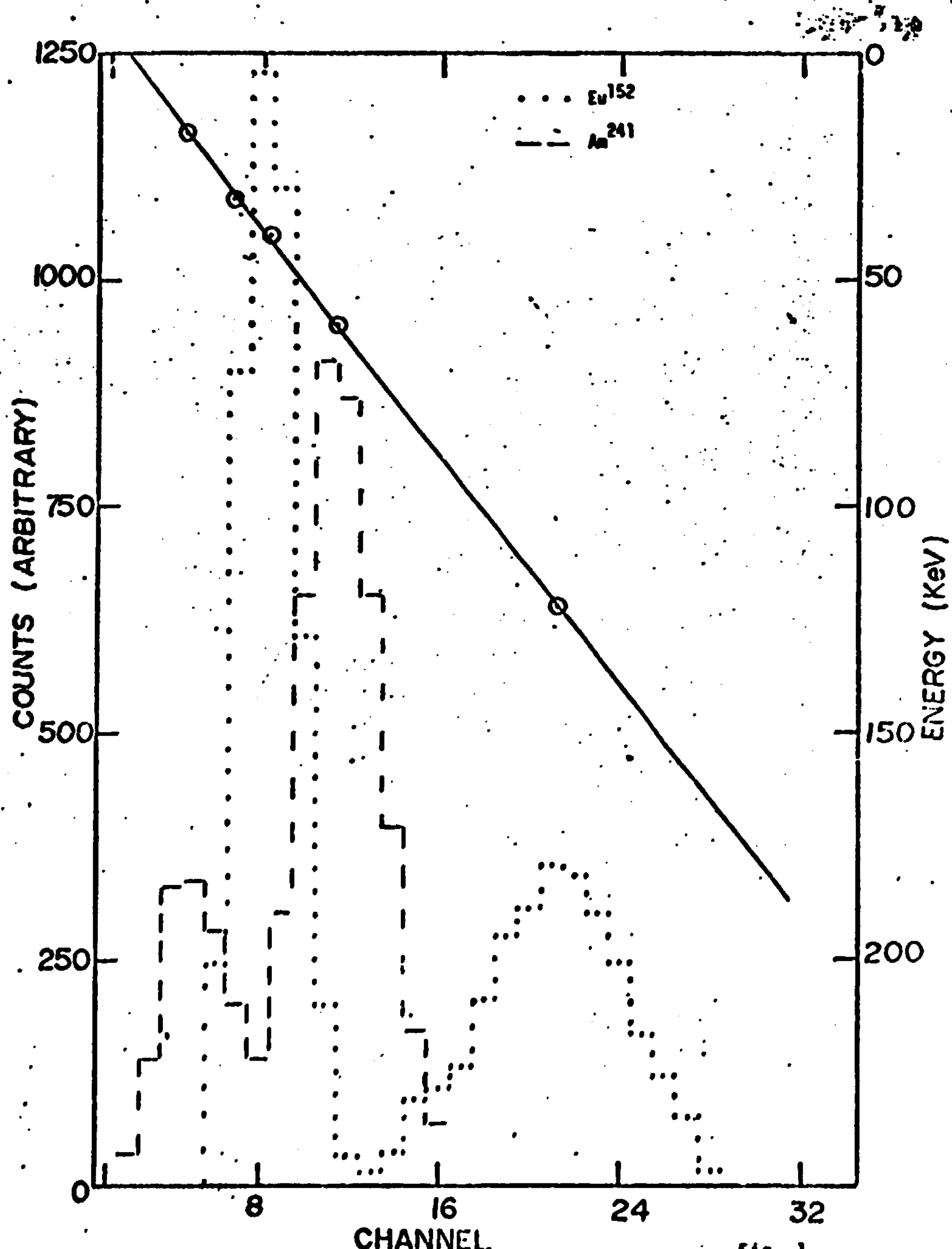

1250
1000
750
500
250
0
COUNTS (ARBITRARY)
8
16
24
32
CHANNEL
0
50
100
150
200
ENERGY (KeV)
Eu152
Am241

Fig. 1

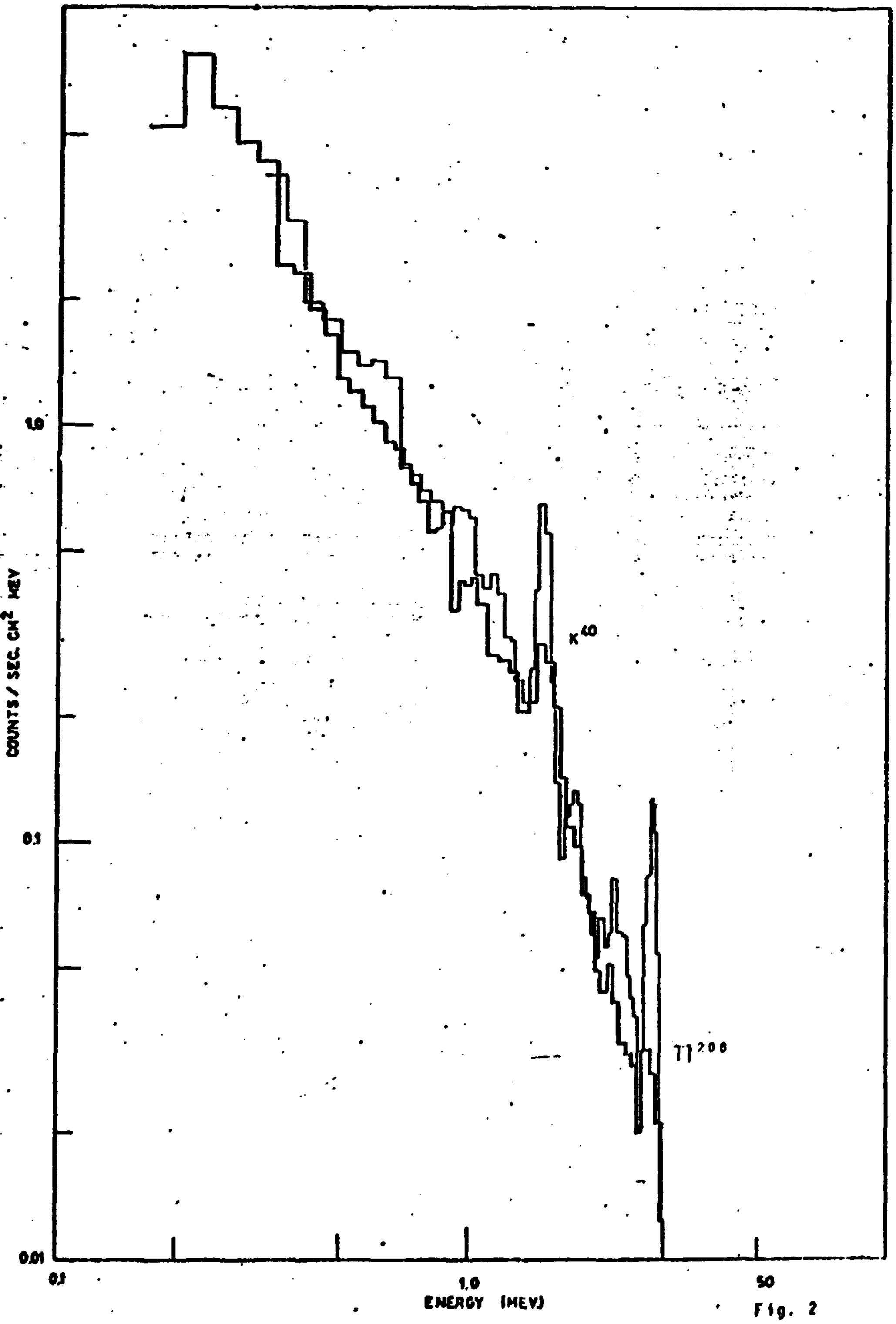
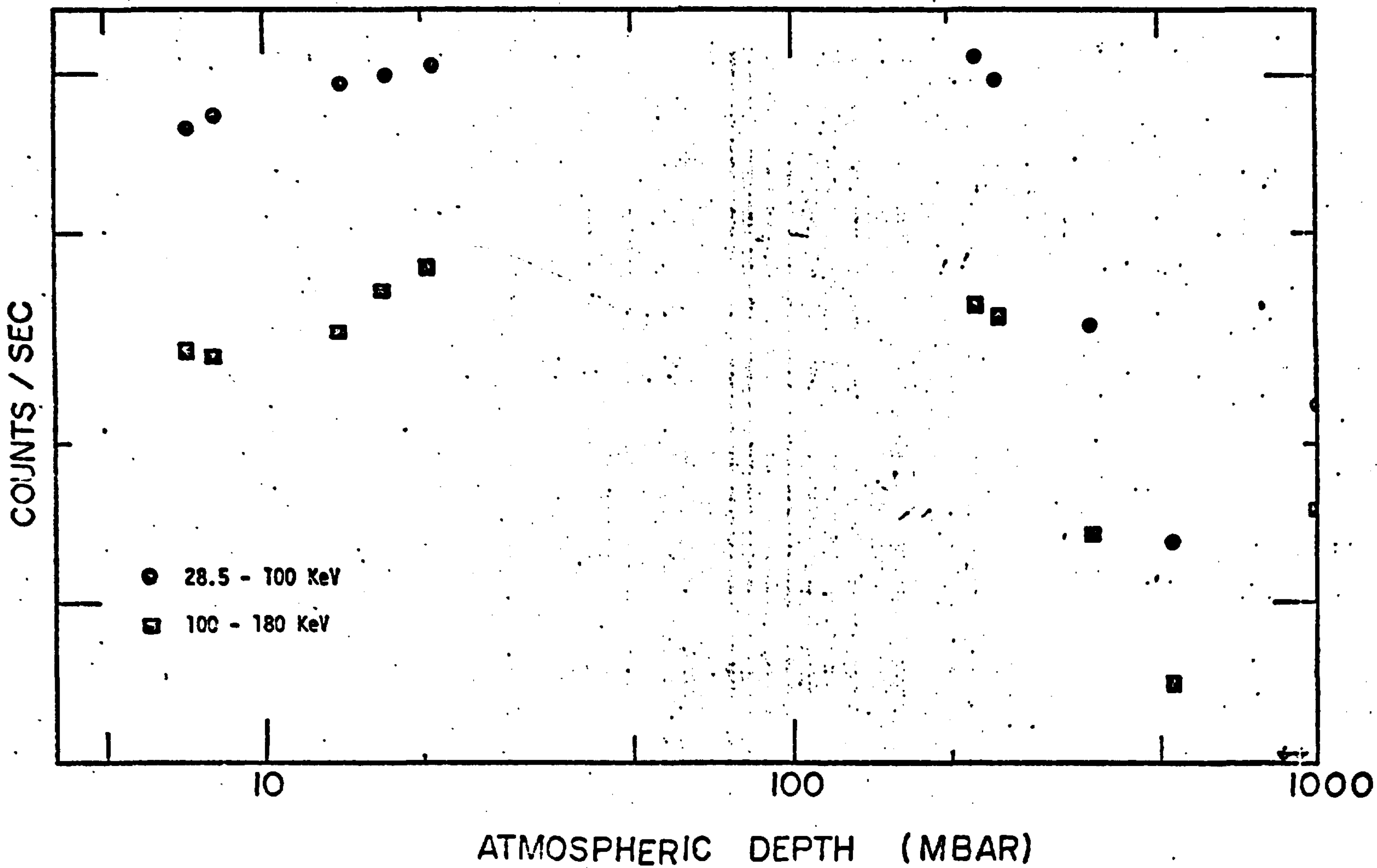
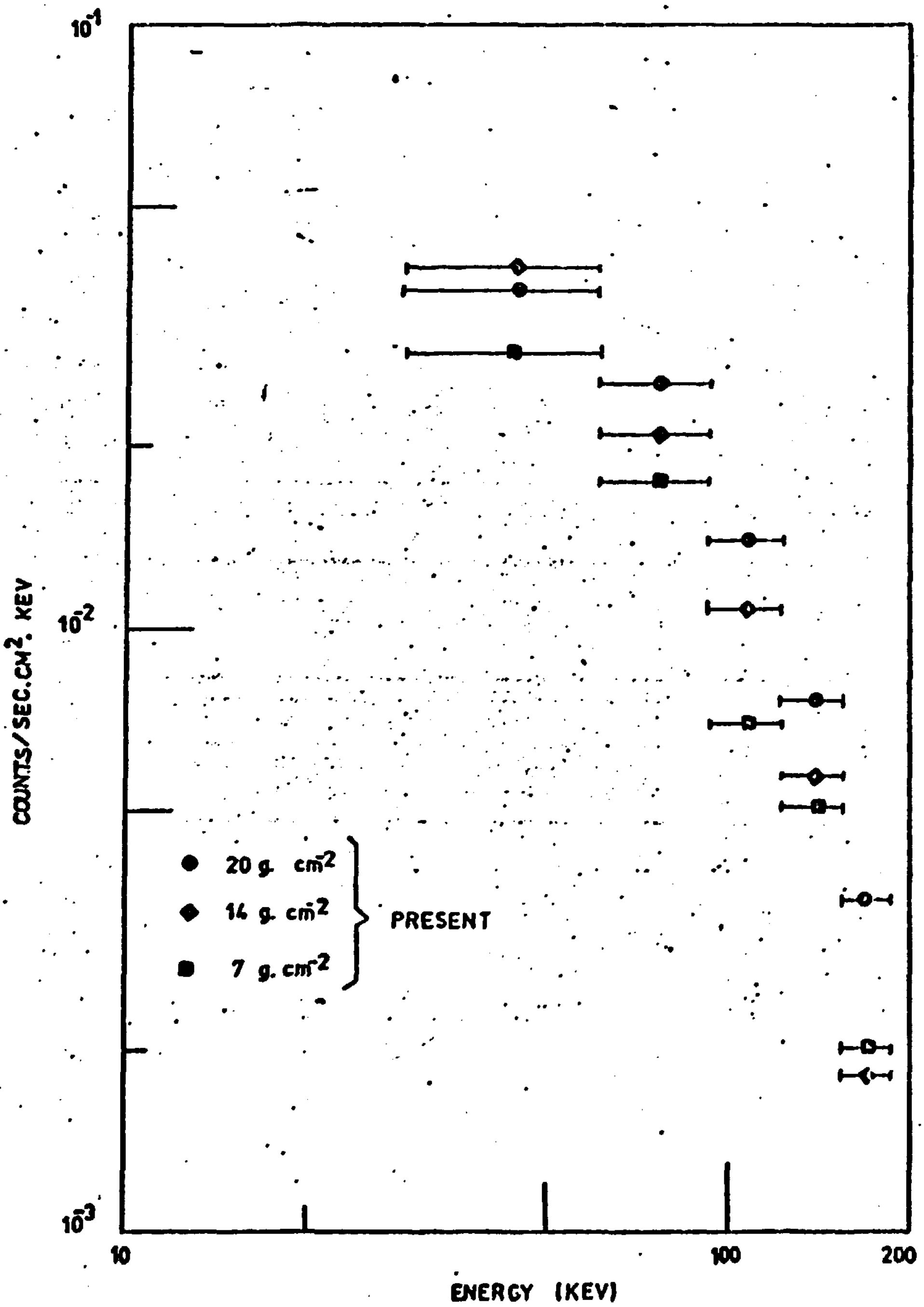



Fig. 2



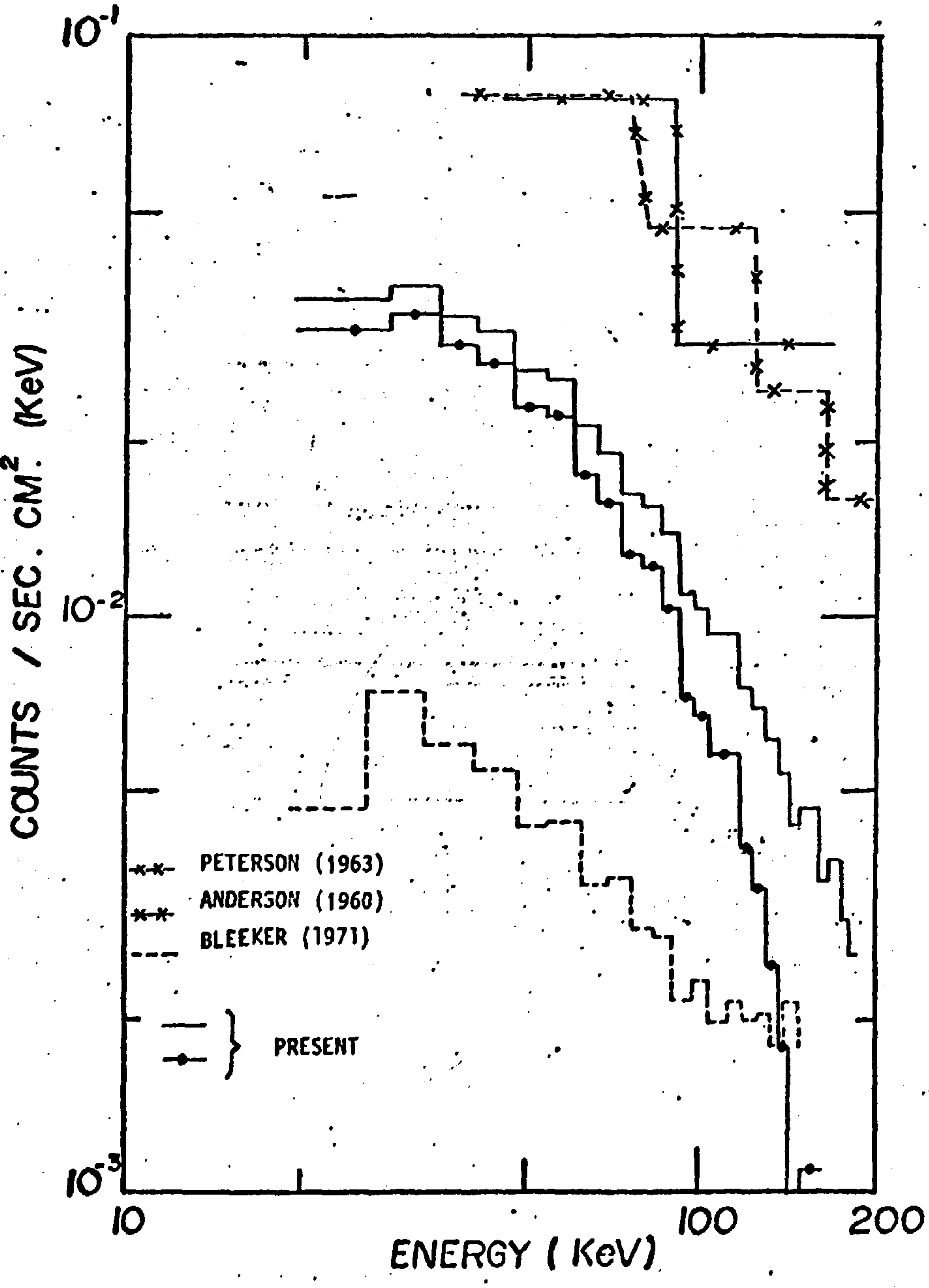
COUNTS / SEC
28.5 - 100 KeV
100 - 180 KeV
10
100
1000
ATMOSPHERIC DEPTH (MBAR)


Fig. 3



10⁻¹
10⁻²
10⁻³
COUNTS/SEC.CM². KEV
20 g. cm⁻²
14 g. cm⁻²
7 g. cm⁻²
PRESENT
10
100
200
ENERGY (KEV)


Fig. 4



10^-1
10^-2
10^-3
COUNTS / SEC. CM.² (KeV)
PETERSON (1963)
ANDERSON (1960)
BLEEKER (1971)
PRESENT
10
100
200
ENERGY ( KeV)


Fig. 5

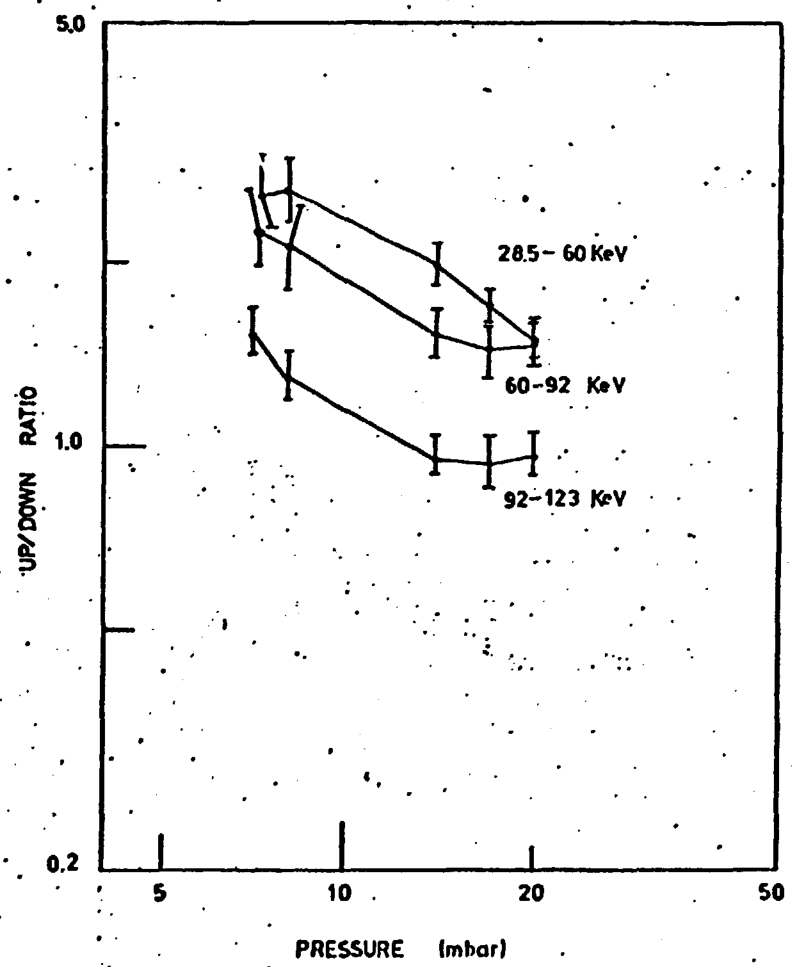

5.0
1.0
0.2
UP/DOWN RATIO
28.5 – 60 KeV
60–92 KeV
92–123 KeV
5
10
20
50
PRESSURE (mbar)

Fig. 6